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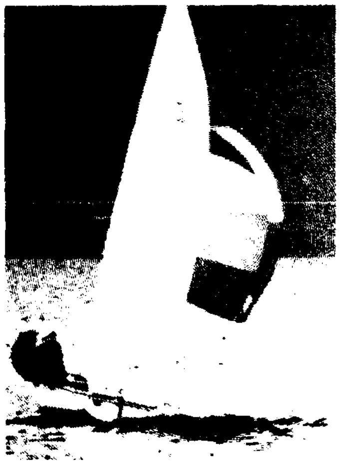

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REPORT ON LYME DISEASE PREPARED FOR US ARMY CORPS OF ENGINEERS FIELD PERSONNEL

by

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13. ABSTRACT (Maximum 200 words)

Lyme disease is an arthropod-borne, bacterial, multisystemic disease. It has assumed importance as an epidemic disease in parts of the United States and in a number of other countries as well. The primary vector of Lyme disease, *Ixodes dammini*, has a widespread distribution in the heavily populated Midwest, Northwest, and Atlantic states, where the tick utilizes small mammals (during the nymphal stage) and deer and other larger mammals, including man (during the adult stage), as food sources. The trend toward rural living among many Americans has further placed humans at risk to attack by the tick and infection with Lyme disease. Initial symptoms of Lyme disease include erythema migrans and arthritis-like pain in the large joints. Serological techniques exist that allow fairly reliable diagnosis, and the bacterium is susceptible to a limited number of antibiotic therapies. Untreated individuals may face severe, chronic, multisystemic involvement, which may, in a few cases, terminate in death. However, most

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patients recover eventually, whether treated or untreated, with no permanent loss of function. The most effective preventative measures that may be taken by individuals at risk include appropriate attire while moving through wooded areas potentially infested with ticks that might carry Lyme disease and examination of the body (especially hair-covered areas) and clothing upon return from the field. Treatment with an acaricide in areas around homes and work sites provides some reduction in local tick populations.

Contents

Preface

The work reported herein was conducted as part of the Natural Resources Research Program (NRRP). The NRRP is sponsored by the Headquarters, US Army Corps of Engineers (HQUSACE), and is assigned to the US Army Engineer Waterways Experiment Station (WES) under the purview of the Environmental Laboratory (EL). Funding was provided under Department of the Army Appropriation 96X3121, General Investigation. The NRRP is managed under the Environmental Resources Research and Assistance Programs (ERRAP), Mr. J. L. Decell, Manager. Dr. A. J. Anderson was Assistant Manager, ERRAP, for the NRRP. Technical Monitors during this study were Ms. Judy Rice and Mr. Robert Daniel, HQUSACE.

Principal Investigator for this work was Dr. William A. Johnson, Assistant Professor of Biology at Nicholls State University, Thibodaux, LA. The report was prepared by Dr. Johnson, who was employed by the WES under an Intergovernmental Personnel Act agreement.

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This study was conducted under the direct supervision of Dr. Cofrancesco, Team Leader, Biomanagement Team, and under the general supervision of Dr. Edwin A. Theriot, Chief, Aquatic Habitat Group; Dr. C. J. Kirby, Chief, Environmental Resources Division; and Dr. John Harrison, Chief, EL, WES.

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1 Introduction

Lyme disease is an important arthropod-borne disease that is spreading rapidly throughout the United States and the world, It is a disease that is often difficult to diagnose, and treatment is not always completely effective. The disease should be of particular concern to individuals who spend a great deal of time in the field, especially in wooded areas. The disease agent, *Borrelia burgdorferi*, is transmitted by the bite of infected ticks. The primary ticks involved are members of the genus *Ixodes*, which are common throughout much of North America. Lyme disease shares a number of features in common with syphilis; it is episodic in nature, it manifests itself in three stages, and it may impact on virtually any body system.

The objectives of this report are to provide USACE field personnel with the most recent information available on Lyme disease, including a brief history of disease transmission by arthropods, the importance of tick feeding behavior, the role of the tick life cycle in disease transmission, a short history of Lyme disease itself, a brief description of the disease agent, Lyme disease symptoms, Lyme disease distribution in the United States, and possible preventative measures that may be taken by field personnel.

Disease Transmission

It has long been known that there is often an association between arthropods and human disease. Most frequently, when the general public thinks of arthropods in relation to disease, they picture insects as the culprits. Mosquitoes, which transmit malaria, a protozoan disease that infects roughly one-half billion humans each year, and fleas, which transmit bubonic plague, a disease that destroyed 20 percent of the human population over a period of about 100 years during the Dark Ages, are examples of insects that are important in transmitting human disease (Yeager 1985). More recently, however, the public has come to recognize another group of arthropods, the arachnids, that are at least as important as the insects as vectors of human disease. Arachnids include, among others, the spiders, mites, and ticks. Mites and ticks are members of the order Acarina.

Mites are important vectors[1] of human disease, particularly in Asia and, to a lesser degree, in Europe. American citizens, however, have only experienced mite-borne diseases (scrub typhus, for example) during military excursions on foreign soil. The American public is usually aware of mites only during "redbug" or "chigger" season, when an immature form of mite causes intense discomfort to those who venture into the field unprepared. Ticks, on the other hand, are recognized as more than just "pests" by even the most uninformed citizens.

Ticks serve as vectors for a number of important human diseases. Rocky Mountain spotted fever (RMSF) is primarily a disease of rodents that is readily transmissible to man by the bite of any of several species of ticks. RMSF is endemic in portions of the Western United States, where it primarily affects adult humans; it also occurs in the Eastern United States, where it is more common in children (Zaki 1989). Other diseases transmitted to humans by ticks include Colorado tick fever in the Western United States, Russian spring-summer encephalitis in Eurasia, Central European encephalitis in Europe, and many others worldwide. Tick-borne disease is a major problem in rural human populations throughout the world.

Feeding and Host Location Structures in Ticks

Acarine and insect vectors are remarkably well adapted to transmitting human diseases. The mosquitoes, the fleas, the mites, and the ticks are all hematophagous (blood-feeding), or, in the case of certain mites, tissue-fluid-feeding organisms. This mode of feeding requires a major deviation from the general form of the structure of the arthropod mouthparts. All of these organisms have piercing mouthparts, as might be expected, but the basic structures involved are often quite different. The piercing mouthparts of the mosquito, flea, and mite are all smooth, piercing structures, while those of the tick are "armed," possessing platelike, spined structures (Figure 1). The spines are located on a structure called the hypostome, the structure that is introduced into the body of the host. In some species the spines can be erected, making forcible removal of the tick difficult. Erection of the spines is important in tick feeding, for feeding typically requires from 2 days to as much as 2 weeks, depending on the species (James and Harwood 1969). If the tick were easily detached from the host upon which it was feeding, the tick's likelihood of survival and successful reproduction would be markedly reduced (Kemp, Stone, and Bennington 1982).

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1 For convenience, definitions of key terms are listed in the Glossary (Appendix A).

Also assisting the tick in its pursuit of an adequate meal is a rather remarkable sensory system. Few ticks possess eyes, and those that do possess only rudimentary vision, using the eyes primarily as photosensory, rather than image-forming, structures. However, in the chemosensory and thermosensory structures, ticks have few peers.

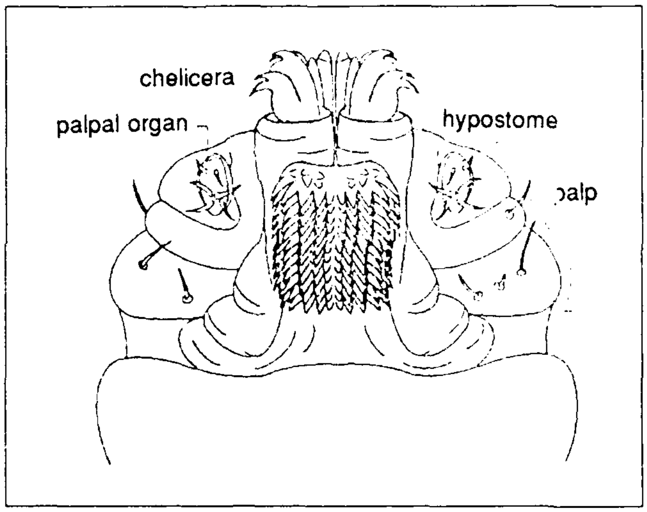


Figure 1. Stylized mouthparts of a typical tick

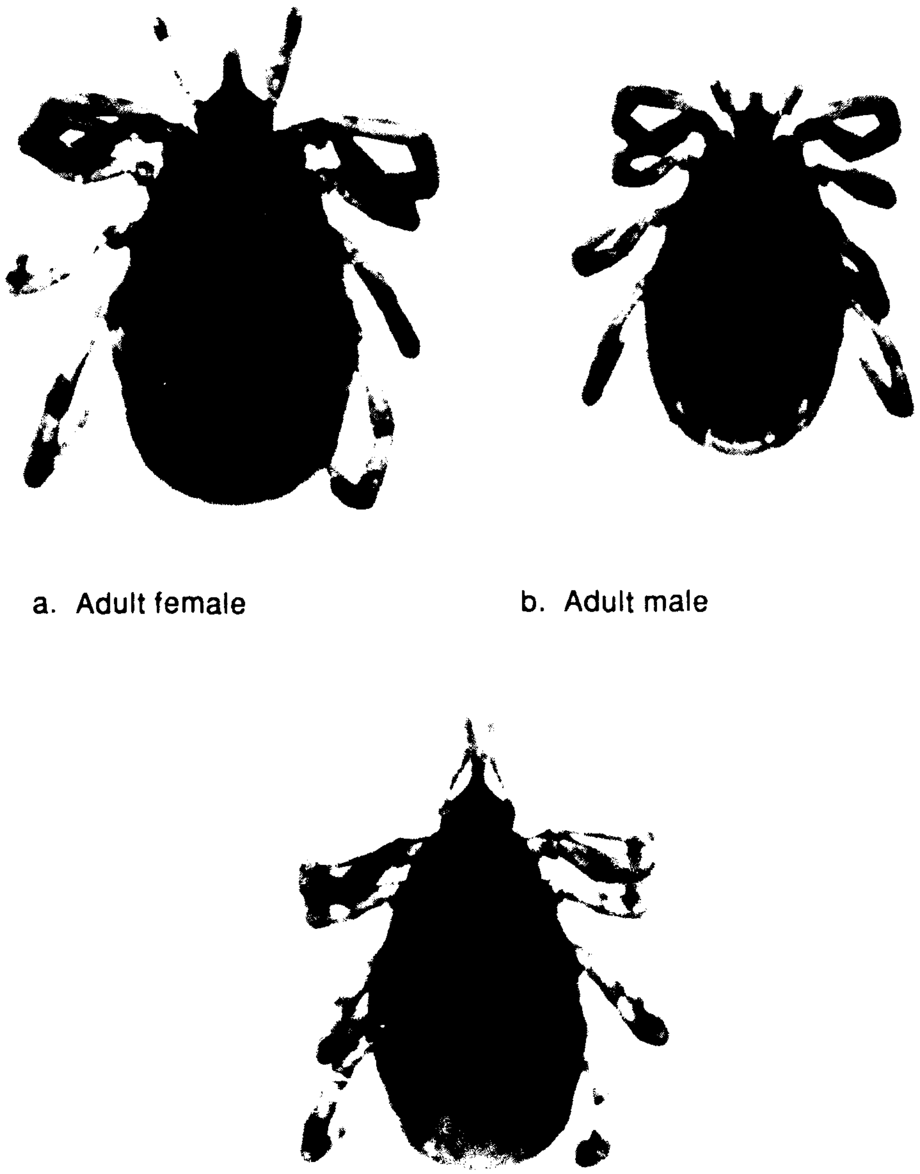
Ticks locate their hosts using their sensory structures in tandem. The eyes, if present, detect the proximity of the host as it passes between the tick and the sun, casting a shadow over the tick. Chemosensory structures on the tick's forelegs, which the tick waves about when in need of a blood meal (a behavior known as "questing"), detect a combination of host odor and changes in carbon dioxide concentration. Once the tick is riding on the host, it uses thermosensory structures located on the hypostome to locate an area where the skin is thin and blood is near the skin surface. When the tick is at the appropriate feeding site, which is generally some portion of the host's body that cannot be easily reached by the host, it pierces the skin of the host, secretes an anticoagulant saliva (which also has some anaesthetic properties), inserts the mouthparts into the wound, and begins feeding. Feeding is a lengthy process because of the nature of the tick's integument, which is stiff and tough, and must slowly unfold to allow filling of the gut with blood (James and Harwood 1970).

It is because the tick introduces its own body fluids into the host that the tick assumes importance as a vector of human disease. Since the tick actually introduces its own secretion into the bloodstream of the host, any disease agent that occurs in the saliva can potentially be introduced into the host's bloodstream (Esslinger 1985). Ticks transmit disease agents to wild animals, domesticated animals and, finally, to humans. In many instances the wild and domestic animal populations may or may not exhibit disease symptoms, but in any case serve as reservoirs of the disease.

The members of the tick family Ixodidae are the most important as vectors of tick-borne disease. In the United States several species of the genera *Dermacentor*, *Amblyomma*, and *Ixodes* are important as vectors of human disease. In Europe, Asia, and Australia, *Ixodes* is the most important ixodid genus, but members of the family Argasidae, especially the genus *Ornithodoros*, are important vectors of human disease.

Life History of Ticks

Understanding the role of ticks in transmitting human disease requires some basic understanding of the life history of ticks (Figure 2). Ticks



a. Adult female

b. Adult male

c. Nymph

Figure 2. Life stages of *Ixodes dammini*

begin life as an egg. In the United States the eggs are usually laid in low mats of vegetation during the fall. The eggs overwinter and hatch into larvae in the spring. Larvae resemble the adult tick, but possess only three pair of walking legs rather than the four pair typical of arachnids. Larval ticks also lack reproductive structures. The larvae seek and find a host animal (often a small rodent), attach, and take a blood meal. The tick may then drop off the host or remain attached; in either case the larval tick undergoes a molt to the nymphal stage (nymphal ticks are often referred to as "seed" ticks).

The molting from the larval to the nymphal stage may require several months. The nymph has four pair of walking legs, like the adult, but lacks reproductive structures. Nymphs take their own blood meal, then typically drop off the host, find a secluded place in the vegetation mat, and enter a period of diapause (a period of inactivity) during which the nymph molts to the adult stage and overwinters.

In the spring or summer, the adult tick may seek out another host (typically a larger mammal, such as a deer, dog, or human) and take another blood meal, or may not feed until the following spring or summer (James and Harwood 1970). Male ticks take only a minute blood meal, or no meal at all. Mating takes place on the host following the adult female's blood meal; then the female drops off the host, finds a suitable vegetation mat, and begins laying eggs. The male dies following mating, and the female dies following egg laying (James and Harwood 1970).

If host individuals fed upon by any of the tick's developmental stages are infected with an appropriate agent of the disease, the chances are good that the tick will become infected during the feeding process. However, transmission of the disease agent depends on several factors. Many disease agents transmitted by ticks are "periodic" in the peripheral blood of the host; therefore, if the tick does not feed during a period of high disease agent periodicity in the host, it is unlikely that the tick will become infected. Also, it has been demonstrated that the longer the tick remains attached to the host, the more likely it is that disease will be transmitted to the tick. In general, nymphal and adult ticks are more likely to transmit the disease to the next host than are larval ticks, and there is a good deal of evidence that, during the molt between the larval and nymphal stage, the disease agents are lost during the molt. Further complicating matters is the fact that, for a number of tick species, the adult female has the ability to transmit the disease agents to her offspring through the eggs (transovarial transmission), ensuring that the new generation of ticks is already infected as it begins life.

Fortunately, in most cases, the disease agent usually drastically impacts the mortality of the developing ticks, so that there is a significant reduction in the population of infected ticks. Even so, the life history pattern of most ticks lends itself to promoting the properly adapted disease agent in the environment.

2 History of Lyme Disease

Early History in Europe

The history of Lyme disease is interesting. In the 1920's, Lipschutz (1923), in Europe, reported on a skin disorder called erythema chronicum migrans (or ECM), in which reddish, circular lines migrated outward from a single locus on the skin, leaving the skin internal to the lines pink in color. Lipschutz attributed this phenomenon to the bite of *Ixodes ricinus*, the "castor bean" tick, a tick with close relatives throughout the world, including North America. Another skin disorder known at the time, acrodermatitis chronica atrophicans (ACA), reported by Herxheimer and Hartman (1902) was later shown to be a progressive form of ECM. Lenhoff (1948) reported the isolation of a spirochete bacterium from the lesions of patients with typical ECM lesions. As syphilis, which is caused by a spirochete bacterium, was amenable to treatment with penicillin therapy, penicillin also came to be used to treat patients with ECM in Europe.

History of Lyme Disease in the United States

Lyme disease was first given status as a separate disease entity in 1977, when Steere and other investigators first described the condition of a cluster of patients from the rural area surrounding Lyme, CT (Steere et al. 1977). All of these patients presented with symptoms commensurate with juvenile arthritis. These same patients were also shown to have experienced erythema migrans (EM) (a symptom indistinguishable from ECM in Europe). Steere used penicillin therapy on some of the patients (Steere, Pachner, and Malawista 1983) and found that those patients complaining of arthritis symptoms with a past history of EM had much better subsequent outcomes than did those patients with the same symptoms not receiving penicillin therapy.

Identification of the Disease Agent and Vector

Burgdorfer and other investigators successfully isolated and identified a spirochete bacterium from the North American tick *Ixodes dammini*, from patients with EM in the United States, from the European tick *Ixodes ricinus*, and from patients with ECM and ACA in Europe (Burgdorfer et al. 1982). The bacterium *Borrelia burgdorferi* was isolated and serologically identified in patients with Lyme disease symptoms in the United States (Preac-Mursic, Wilske, and Schierz 1977; Steere et al. 1983; Benach et al. 1987). These findings provided the information that had heretofore been missing from the Lyme disease picture.

Lyme disease has been shown to be responsible for multisystem disorders including, but not limited to, cardiac dysfunction (Steere et al. 1980, Marcus et al. 1985), peripheral nerve lesions and multifocal brain involvement, including meningitis (Reik et al. 1979, Pachner and Steere 1985), joint dysfunction (Steere et al. 1979), eye involvement (Bialasiewicz et al. 1988), musculoskeletal disorders (Kolstoe and Messner 1989), hepatitis (Goellner et al. 1988), and respiratory distress syndrome in adults (Kirsh, Ruben, and Steere 1988). In this multisystemic involvement, Lyme disease is much like syphilis, another spirochetal disease. Also like syphilis, Lyme disease displays a chronological sequence of development at three levels: (a) local erythema migrans; (b) multisystemic infection; and (c) chronic system-wide infection, degenerative disorders of multisystemic regions, and possible mortality (Zaki 1989).

3 Disease Agent and Symptoms

The Disease Agent

The agent of Lyme disease is *Borrelia burgdorferi*, a spirochete bacterium. The bacterium is fastidious in nature, making it difficult to grow in the laboratory; it can be cultured only on Barbour-Stoenner-Kelly culture medium. The bacterium's infectivity spontaneously disappears after 10 to 15 generations in culture, but in nature its infectivity is maintained from generation to generation without diminution (Schwan, Burgdorfer, and Garon 1988).

One particularly troublesome characteristic of the bacterium involves its genetic mechanism. Like most bacteria, *B. burgdorferi* possesses a circular "chromosome" composed of double-stranded DNA. However, unlike most bacteria, it also contains plasmids (small, circular, double-stranded "pieces" of DNA that are inherited independently of the chromosomal DNA). It is thought that these plasmids code for at least some of the disease-causing components of the bacterium (Schwan, Burgdorfer, and Garon 1988; Hyde and Johnson 1988). In addition to being independently inherited, plasmids are more susceptible to mutation than is the chromosomal DNA. Plasmids are thus more capable of evolving in response to the immune system of the host, making it less likely that the immune system of the host will be able to cope with the bacterium in a normal fashion. If the bacterium loses its infectivity, it can be demonstrated that the plasmids of the bacterium have been lost as well (Schwan, Burgdorfer, and Garon 1988; Hyde and Johnson 1988).

Lyme Disease Symptoms

Typically, Lyme disease occurs in stages. Each stage exhibits several clinical manifestations. Using Steere's terminology (Steere 1989), these stages are: (a) early infection: Stage 1, (b) early infection: Stage 2, and (c) late infection: Stage 3.

Early infection: Stage 1

This stage is characterized by erythema migrans; after a host is bitten by an infected tick, *B. burgdorferi* spreads locally in the skin. During this time the bacterium can be recovered from the skin lesions themselves in 60 to 80 percent of the patients. It is during this period that the patient occasionally suffers fevers and local lymph node enlargement. Erythema migrans typically disappears spontaneously within 3 to 4 weeks, but may persist longer and recur periodically (Steere 1989).

Early infection: Stage 2

This stage is characterized by a rapid spreading by the bacterium in the blood and lymph to many tissues. It is during this stage that the bacterium can be most readily recovered from the blood of infected patients. In smaller numbers, the bacterium has also been recovered during this stage from cardiac muscle, skeletal muscle, bone, joints, the retina of the eye, spleen, liver, meninges, and the brain (Duray and Steere 1988). Studies using rats experimentally infected with *Borrelia burgdorferi* demonstrate that all organs harbor the bacterium within 5 days following inoculation. Over time, however, the bacterium disappears from these organs (Barthold et al. 1988); it is assumed that the same phenomenon is true for humans, as well (Steere 1989).

The tissues involved in humans are too numerous to list here, but several manifestations are more common than others. Skin involvement, and of the musculoskeletal and nervous system, is typical. A significant number of patients suffer severe headaches and stiffness of the neck; however, these are episodic in nature, rarely lasting more than a few hours, with several hours free of such symptoms before the next episode. In this respect *B. burgdorferi* is much like its congener *B. duttoni*, the causative agent of relapsing fever. During this stage of the disease, patients complain of migratory joint pain, as well as severe fatigue and malaise. Except for the fatigue and malaise, most symptoms are intermittent in nature (Steere 1989). One of the mysteries concerning B. *burgdorferi* is its ability to establish itself in certain sites within the body. It has been suggested (Steere 1989) that perhaps the organism coats itself with a slime layer that renders the bacterium "invisible" (by incorporating host proteins into the slime layer) to the host's immune system.

In the United States roughly 20 percent of infected patients develop involvement of the central nervous system (CNS). Symptoms associated with CNS involvement include torpor, memory loss, and mood swings. Facial palsy (either unilateral or bilateral), indistinguishable from Bell's palsy, is the most common cranial neuropathy, but peripheral nervous system involvement is common as well, as is lower spinal cord pain. In Europe the most common symptom of CNS involvement is pain in the lower spinal cord and spinal nerves, known as radicular pain (Steere 1989).

Shortly after the onset of the disease, 4 to 8 percent of patients experience cardiac involvement. The most common cardiac dysfunction is complete heart block (Steere 1989). It is usually short-term, and most patients recover from this symptom within a few days. However, some patients die as a result of heart block or one of the less common cardiac involvements such as pericarditis or pancarditis (Marcus et al. 1985). Other significant problems during stage 2 include fatal adult respiratory distress syndrome, recurrent hepatitis, osteomyelitis, or retinal involvement and detachment. Several months after the onset of the disease, roughly 60 percent of patients begin to experience episodic muscle, joint, and bone pain. Arthritis is common, but usually involves only one or two of the larger joints, especially the knee (Steere et al. 1987).

Late infection: Stage 3

This stage is characterized by episodic arthritis, with the episodes increasing in length with each recurrence (Steere et al. 1987; Lawson and Steere 1985; Steere et al. 1979). Episodes may last months or even years in some individuals. Again, it is most commonly the knee joints that are involved. In most cases, even those individuals that have suffered the most long-term arthritic symptoms become symptom free (Steere et al. 1987). For many patients, the most common long-term evidence of continued infection is the development of ACA, which is most commonly observed in Europe. Frequently, ACA occurs at the same site where EM occurred years earlier. In a significant number of patients, highly keratinized skin lesions, indicative of scleroderma (a skin disorder characterized by hard, thickened layers of heavily keratinized epidermis) occur along with ACA (Herzer 1983).

A factor complicating Lyme disease is that *B. burgdorferi* has the capacity to cross the placental membrane between a pregnant female and her unborn child. Two infants are known to have died as a result of transplacental transmission--one due to improper development of the heart, and one to complications from encephalitis (Markowitz, et al. 1986). Despite this, a recent study of 463 infants from areas endemic and nonendemic for Lyme disease was unable to establish any correlation between congenital defects and the presence of identifiable *B. burgdorferi* antibodies. Therefore, it appears that while the bacterium can cause fetal abnormalities, and even death, this is an unusual outcome (Williams et al. 1988).

4 Distribution of Lyme Disease in the United States

Historical Distribution

The first known report of probable Lyme disease in the United States came from central Wisconsin in 1970, when an individual known to be bitten by a tick presented with classic erythema migrans (Scriminti 1970). In 1975 several patients presenting with arthritis symptoms were reported by Steere, from rural areas around Lyme, CT (Steere et al. 1977). In 1982, investigators successfully isolated and cultured *Borrelia burgdorferi* from the tick *Ixodes dammini*, common along the eastern seaboard (Burgdorfer et al. 1982). In the association of the causative agent of Lyme disease with ticks, several other tick species, spanning the rest of the United States in their distribution, have been shown to serve as potential vectors. *Ixodes dammini* in the Northeast and Midwest, *Ixodes pacificus* in the West, and *Ixodes scapularis* in the Southeast have all been shown to serve as vectors for Lyme disease. Other tick species known to harbor *B. burgdorferi* include *Amblyomma americanum*, *Dermacentor albipictus*, *Dermacentor variabilis*, *Ixodes dentatus*, *Ixodes cookei*, *Ixodes trianguliceps*, and *Haemaphysalis leporispalustris* (Burgdorfer 1989).

The greatest focus for Lyme disease in the United States is in the Northeast and Atlantic states, but many cases are known from a number of states, particularly in the upper Midwest (notably Minnesota and Wisconsin), the far West (California), and the Southeast, especially Georgia (Ciesielski et al. 1989). As of October 1989, Lyme disease had been reported in 43 of the 48 contiguous states, according to Oliver (1989) (Figure 3).

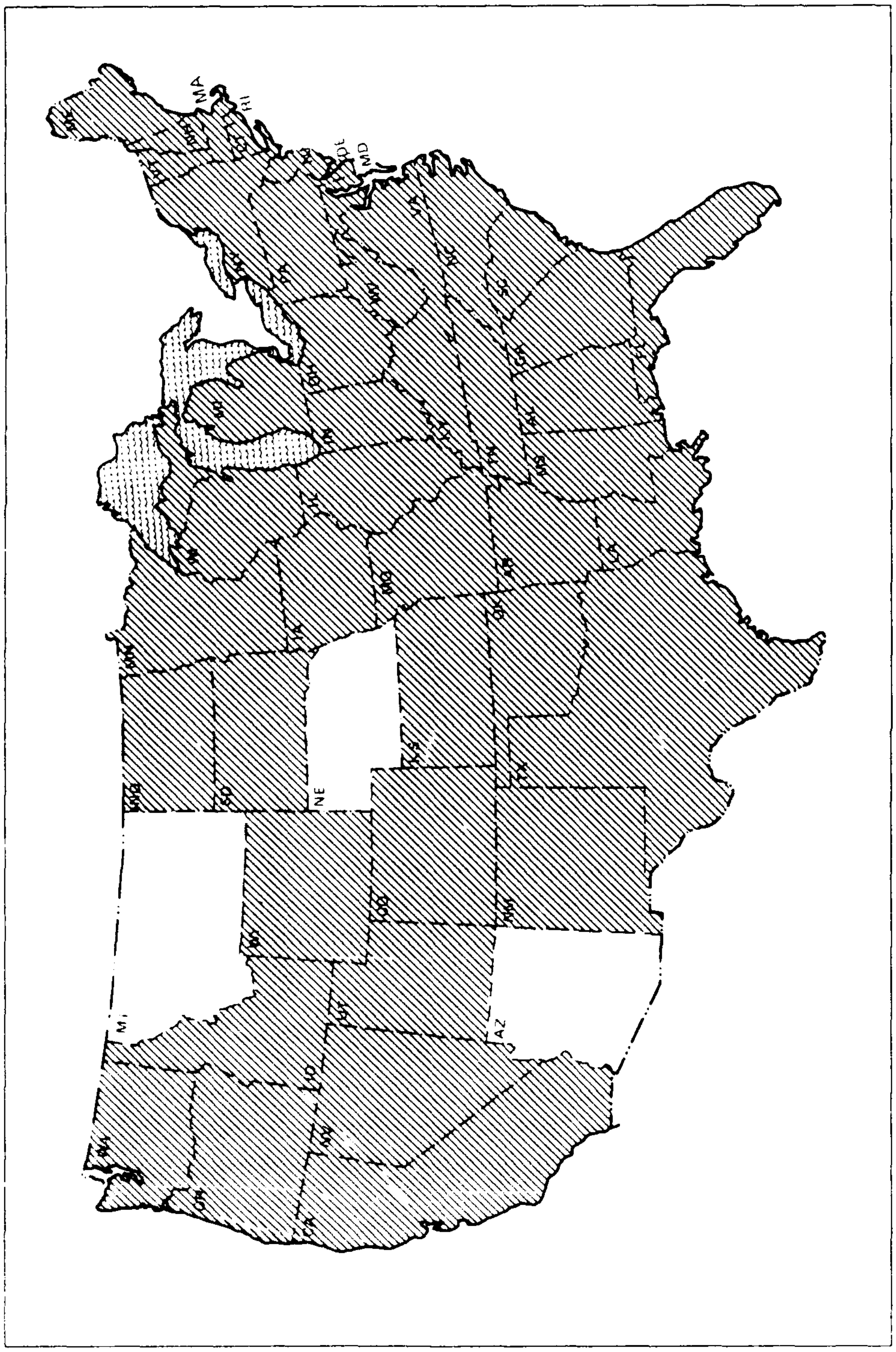


Figure 3. Occurrence of Lyme disease in the United States (shaded areas)

Reasons for Increased Incidence of Lyme Disease

The major reasons for the increased incidence of Lyme disease in the United States are linked to human behavior rather than to the evolution of some new disease agent, evolution of some new infection mechanism, or aberrations in tick behavior. It is extremely likely that the Lyme disease agent has been in the United States for hundreds or thousands of years (Oliver 1989). What factors, then, are responsible for the almost epidemic outbreak of Lyme disease in this country?

Movement of humans to suburban and rural areas

The movement of large numbers of human beings from urban areas into surrounding suburban and rural areas in recent years, particularly throughout the 1960's and 1970's, has resulted in much greater numbers of tick bites than would otherwise be expected. Clearing of large tracts of forestland for new development would seem initially to lead to a drastic reduction in tick numbers, as habitat available for deer and other large mammals is reduced. But, in many cases, we may see an actual increase in tick population density (Wilson 1986). As deer and other large wild mammal species are excluded from an area, ticks often move about, seeking appropriate hosts. In many cases, exclusion of deer populations from a developed area results in the ticks moving into transition zones between woodlots and homesites. Dogs and humans now enter the ticks' foodchain in place of the absent deer, and the likelihood of Lyme disease spreading through the human population is greatly enhanced. Furthermore, infected dogs serve as reservoir species, maintaining the disease agent in proximity to the human population. In areas where extensive wooded tracts remain near human housing, even the lawns may harbor extensive tick populations, as a result of fed ticks dropping off the deer and finding a suitable vegetation mat, in this case, closely trimmed lawns in residential neighborhoods (Schulze, Parkin, and Bosler 1988).

Recent increases in outdoor activities

Since the 1950's there has been a significant increase in recreational hunting, particularly deer hunting. Responding to this increased interest in hunting, local and State agencies have sought to increase deer populations. In many cases, deer were physically removed from one geographic region (the Southeast, for example) and moved to another (the Northeast or Midwest). During much of the time when these wildlife "seedings" took place, the importance of deer serving as reservoirs to maintain a potentially dangerous human disease in nature was unknown or ignored (however, according to Telford et al. 1988, some evidence still suggests that white-tailed deer are incompetent as reservoirs of the Lyme disease agent). Thus, it is possible that much of the rapid spread of Lyme disease

across the United States may be attributable, at least in part, to game management techniques, such as moving deer from one region to another (Schulze et al. 1988). In any case, the influx of large numbers of deer into areas where *Borrelia burgdorferi* had previously been maintained at low levels allowed for a population explosion of infected ticks once large numbers of suitable hosts became available. Larger numbers of deer equate with larger numbers of deer hunters, leading to an increasing rate of exposure to the tick vectors of Lyme disease. Studies in the Northeast have demonstrated that where the white-tailed deer population is large, the population of *Ixodes dammini* is large as well, and where the deer population is small or nonexistent, the population of *I. dammini* is small or absent (Wilson, Levine, and Spielman 1984). Anderson (1989) noted that attempts to eliminate deer from areas of human settlement may pose some problems as well. Eliminating deer requires the implementation of either drastic overharvesting or the construction of barriers between areas of human and deer habitats. Overharvesting is, in general, not popular with many segments of human society (hunters and conservationists, among others), and several studies have shown that unless deer populations are almost totally eliminated, little impact on tick population density is obtained (Anderson 1988; Wilson, Levine, and Spielman 1984). Finally, the expense of constructing barriers that would prevent deer from entering surrounding areas would be enormous, and many humans would find such barriers to be aesthetically unpleasant. Thus, elimination of deer populations does not appear to be feasible at this time.

Apparently, the behaviors of ticks, deer, and humans are such that exposure to Lyme disease will be a problem for some time. Efforts to control Lyme disease should perhaps then be focused on utilization of avoidance techniques to prevent tick bites and, where feasible, on attempts to control tick populations locally.

5 Avoidance Techniques

Those individuals most at risk for contracting Lyme disease are of course those who spend the greatest amount of time in the field, especially in tick-infested areas. For personnel at the Federal, State, and local levels whose occupations demand fieldwork, several steps may be implemented.

Surveying Ticks on Managed Lands

Surveys of recreational areas where such personnel work can be conducted to determine whether likely tick vectors of Lyme disease are abundant. While labor-intensive, such surveys do an adequate job of determining relative abundance of ticks in general (Falco and Fish 1989). Such surveys involve establishing transects through areas and walking through, dragging a 1-m square of flannel cloth attached to a handle. At the end of the transect, ticks can be removed from the cloth, preserved, and later identified by qualified personnel (Milne 1943). By correlating the number of tick encounters with the length of the transect, a general idea of tick population densities can be obtained. While other methods for sampling tick populations are available (carbon dioxide traps or host-animal trapping, for example), the least labor-intensive and the most revealing is survey by drag sampling (Wilson et al. 1972; Main et al. 1982).

Avoiding Tick Bite

Once areas of high vector tick population have been identified, a number of steps can be taken by personnel to significantly reduce the incidence of tick bites and possible exposure to Lyme disease. Proper adjustment of clothing is a useful way of reducing opportunities of tick bite. The wearing of long-sleeved shirts (with the sleeves buttoned), buttoning the collars of shirts, and wearing long trousers may seem an inconvenience, particularly in the Southern and Western states during the warmer months, and may cause some discomfort. However, inconvenience and discomfort are preferable to Lyme disease. Even after taking these

precautions, personnel should carefully examine skin and clothing upon their return to offices or residences (Oliver 1989). Once on a host, many ticks do not immediately embed. Instead, they generally wander around "searching" for a suitable site for feeding. Often such a site is in a position difficult for the host to reach. It is best, therefore, to have another individual assist in carrying out inspections (particularly on the back, nape of the neck and head). In the process of biting and feeding, ticks introduce a local anaesthetic that often renders the bite unnoticeable; therefore, proper inspection is extremely important. As previously mentioned, ticks generally require several days to take a complete blood meal; often the disease agent must migrate from the tick's midgut to its salivary glands during feeding. This migration by the disease agent takes at least 24 hr. Therefore, even if the tick is embedded and feeding, transmission of the disease rarely takes place immediately, allowing a safety margin for the host of several hours (Piesman and Sinsky 1988).

Use of Tick Repellents

Coupled with proper clothing, tick repellent treatment is also a useful method of avoiding bites by potential tick vectors. Permethrin (trade name: Permathone), while currently under review in a number of states, is licensed for use as an aerosol for the treatment of clothing in 26 states. Permethrin is to be applied only to clothing , never directly to the skin, and must be allowed to dry prior to wearing the clothing. It must also be applied in a well-ventilated area, as it has toxic qualities for humans as well as ticks. Permethrin is very effective as a tick repellent (Oliver 1989). N, N, diethyl-m-toluamide (DEET), another tick repellent, is also quite useful, though not as effective as permethrin. However, DEET can be applied directly to the surface of the skin (Oliver 1989).

Removal of Embedded Ticks

If embedded ticks are found, they should be carefully removed as soon as possible, as disease transmission has been shown to be related to the length of time the tick remains embedded in the host. The tick should be grasped by fine-pointed forceps as closely to the skin as possible. Attempts should be made to avoid squeezing the body of the tick; otherwise, contaminated body fluids of the ticks can be introduced inadvertently into the host's tissues. The tick should be removed by pulling straight out from the skin in one smooth motion, applying only as much force as is necessary to remove the tick. Jerking or pulling the tick from side to side or up and down may result in the mouthparts breaking off and remaining embedded in the skin of the host. Serious secondary infection can result if portions of the tick remain in the host; also, the mouthparts may be

contaminated with the Lyme disease agent, enhancing the potential for infection with Lyme disease.

Local Control of Tick Populations

Another method of decreasing the incidence of exposure to tick vectors of Lyme disease is to alter the local environment. Several methods may be used to locally control tick populations.

Controlled burning

Controlled burning of infested woodlots has been shown to be effective in some instances. Burning reduces the amount of habitat available to potential reservoirs of Lyme disease. Another favorable aspect of burning is that it reduces the amount of vegetation mat available to tick eggs, larvae, and nymphs (Wilson 1986). The vegetation mat is important in tick development because of the locally high humidity. Burning the vegetation lowers the local humidity to levels that are inhospitable to tick development. One detrimental aspect of controlled burning is that under certain conditions significant numbers of ticks may survive the burning, and, in the absence of wild mammal hosts may move into areas of human habitation. This has the effect of actually increasing the likelihood of ticks feeding on humans and domestic mammals over what would have occurred in the absence of burning (Wilson 1986).

Acaricide treatment of infested areas

In addition to controlled burning, the total environment can be modified by the application of acaricides (pesticides that kill ticks and mites). Two acaricides, carbaryl and diazinon, have been shown to be effective against *Ixodes dammini* and are probably effective for most other ixodid ticks as well. In one study (Schulze, Parkin, and Bosler 1988), high-pressure hydraulic spraying in wooded areas known to harbor high densities of *I. dammini* drastically reduced the population of ticks; however, there was no statistical difference between tick densities in treated and untreated areas during the following fall. One of the problems associated with attempting to control tick populations with acaricides is that ticks rely on a variety of wild and domesticated mammals for blood meals. This characteristic of ticks makes attempts to poison the ticks over large areas difficult at best. One method that has shown some promise for controlling larval and nymphal tick populations has been the dispersal of permethrin-impregnated cotton balls over large areas (Mather, Ribeiro, and Spielman 1987). Rodents readily incorporate the treated cotton in their nesting materials. Ticks feeding on the rodents are thus poisoned on the site, and in some regions, captured white-footed mice in treated areas were 72 percent free of ticks. This technique shows considerable promise

in areas where tick vectors are present in high population densities. Of course, as with all chemical control measures, the possibility of adverse environmental and health impacts must be considered. Whether chemical control is a viable alternative for Lyme disease control as a general practice remains questionable. At the present time, efforts by individuals to avoid being bitten by ticks is probably the best alternative.

6 Summary

Lyme disease, a new contender in the arena of human diseases, is caused by *Borrelia burgdorferi*, a spirochete bacterium that is capable of causing serious human disease as well as causing infections in wild and domesticated animals. The causative agent is transmitted by the bites of ticks, predominantly of three species in the United States: *Ixodes dammini*, *Ixodes pacificus*, and *Ixodes scapularis*. The feeding strategies and life histories of ticks, in general, make them well-suited to serve as vectors of disease. The existence in the natural environment of small rodents (primarily the white-footed mouse, *Peromyscus leucopus*), which do not contract Lyme disease but serve as reservoirs for the disease, further complicates the problem. The larval and nymphal stages of tick vectors of Lyme disease feed on this population of rodents, thus maintaining a continuing cycle of the disease in nature. The increasing movement of the human population into suburban and rural settings results in greater exposure to the disease than would otherwise occur. Management of deer populations by increasing deer numbers for recreational hunting further enhances the likelihood of human exposure to tick bites.

Borrelia burgdorferi is an insidious bacterium with a number of features that promote its disease-causing potential. Externally, there is a slime coat that probably allows the bacterium to attach to host cells and to exhibit endotoxic characters. The possession of extra-chromosomal DNA (plasmids) that are probably responsible for the inheritance of disease-causing substances and the ability to respond to the host immune system by mutating further facilitate the bacterium's disease potential, as well as contributing to the "mimic" quality of the disease.

Lyme disease is characterized in its early stage by erythema migrans (a skin lesion often associated with tick bites) and, in a significant percentage of patients, symptoms of rheumatoid arthritis. In its second stage, Lyme disease agents migrate through the blood and lymph to virtually all body systems, causing a variety of symptoms. In its final stage, Lyme disease can result in serious, debilitating, degenerative dysfunction of a variety of body systems, including the cardiovascular system, the nervous system, the musculoskeletal system, etc. Diagnosis of Lyme disease is difficult because the symptoms of the disease may mimic a variety of other disorders. While Lyme disease may have a fatal outcome, this is unusual,

and for most patients antibiotic therapy, especially oral tetracyclines and intravenous penicillins, brings about a permanent cure for the disease.

Lyme disease is widespread throughout the world and is becoming a significant health problem. It has been reported in 45 of the 48 contiguous states, and may already be present in all of the lower 48 states. Avoidance of Lyme disease entails nothing new for field personnel and outdoorsmen. Steps should be taken to avoid tick bite, including (a) avoidance of areas known to be infested with ticks, if possible, (b) use of tick repellents, (c) wearing of clothing that gives some protection against tick access to the skin, (d) inspection of the body immediately upon returning from the field, and, (e) if conditions are suitable, acaricide treatment of the environment around housing and on domestic animals near known tick-infested areas. With the application of good sense, protection from potential tick vectors of Lyme disease is possible.

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Appendix A
Glossary

Acrodermatitis chronica atrophicans - a chronic (long-term) skin disorder occasionally associated with tick bites, characterized by atrophy of the upper layer of the skin.

Carbaryl - a general pesticide that has demonstrated some effectiveness in killing acarines.

DEET - N,N,diethyl-m-toluamide, trade name Delphene. An insecticide that is an effective acaricide when applied to clothing and the surface of the skin.

Diapause - behavioral pattern exhibited by *many* arthropods that involves an interruption in the normal activity of the organism.

Diazinon - a general pesticide that has demonstrated some effectiveness in killing acarines.

Erythema chronicum migrans - a skin lesion essentially identical to erythema migrans, but persisting for months or even years, seen mostly in Europe.

Erythema migrans - a skin lesion associated with the bite of certain ticks, characterized by a migration of inflamed tissue radially outward from the original bite site, usually a transient phenomenon.

Hematophagous - blood-feeding.

Hypostome - the principal feeding apparatus located on the capitulum (headlike structure) of acarines.

Permethrin - an effective acaricide, trade name Permethone, that is extremely toxic, and must not be applied directly to the surface of the skin.

Plasmid - a sequence of genes that are separate from, and not associated with, the chromosomal genes of an organism.

Questing - a behavioral activity exhibited by ticks that facilitates host-finding; during the activity the tick climbs to the top of a vegetation mat and moves its forelegs in the air.

Reservoir - an organism that maintains a population of disease agents in nature, while not necessarily acquiring the disease.

Scleroderma - a skin condition characterized by excess keratinization of the tissue, resulting in a hardened, nonsensitive mass on the surface of the skin.

Transovarial transmission - the process by which an infected female vector passes a disease agent to her offspring through the membranes of the ova.

Vector - an organism that transmits a disease agent to another organism.